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Research Article

Development of a MOF Based Potentiometric Sensor for Determination of Rhodamine B

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Abstract

Rhodamine B (RB) is a basic, red, and cationic dye belonging to the class of xanthene dyes. Rhodamine B is harmful to human and animal health when ingested or is in contact with the skin. It causes irritation to the skin, eyes, and respiratory tract. Experimental studies have shown that Rhodamine B exhibits carcinogenicity, reproductive and developmental toxicity, neurotoxicity, and chronic toxicity in humans and animals. In this study, a Rhodamine B-selective potentiometric sensor was developed by using MIL-53 (Al) (Material Institute Lavoisier) as the ionophore in the prepared membrane composition. The sensor, prepared with a membrane composition of 6% MIL-53 (Al), 26% PVC (Polyvinyl chloride), and 68% DOS (bis(2-ethylhexyl) sebacate), exhibited the best potentiometric performance. The Rhodamine B-selective sensor exhibited a linear response in the concentration range of 1.0×10^{-6} M to 1.0×10^{-2} M with a slope of 58.0 mV/decade and a detection limit of (LOD) 5.0×10^{-7} M in Rhodamine B solutions adjusted to pH 4.50. The response time of the Rhodamine B-selective sensor was less than 5 seconds and was unaffected by hydronium ions in the pH range of 4.49 to 8.08. Analytical application of the sensor was successfully carried out in Van Lake, wastewater, and tap water.

Keywords: Determination of Rhodamine B, metal organic framework, **p**otentiometric sensor

Rodamin B Tayini için MOF Temelli Potansiyometrik Sensör Geliştirilmesi

Öz

Rodamin B (RB), ksanten boyaları sınıfına ait bazik, kırmızı ve katyonik bir boyar maddedir. Rodamin B, ağızdan alındığında veya deri ile teması halinde insan ve hayvan sağlığı için zararlıdır. Ciltte, gözlerde ve solunum yollarında tahrişe neden olur. Deneysel çalışmalar, rodamin B'nin insanlarda ve hayvanlarda kanserojenlik, üreme ve gelişimsel toksisite, nörotoksisite ve kronik toksisite sergilediğini göstermiştir. Bu çalışmada, hazırlanan membran bileşiminde iyonofor olarak MIL-53 (Al) (Material Institute Lavoisier) kullanılarak Rodamin B-seçici potansiyometrik sensör geliştirildi. %6 MIL-53 (Al), %26 PVC (Polivinil klorür), %68 DOS (Bis(2-etilhekzil) sebakat) membran bileşimi ile hazırlanan sensör en iyi potansiyometrik performans özelliği sergiledi. Rodamin B-seçici sensör, 1.0×10^{-6} M-1.0×10^{-2} M konsantrasyon aralığında pH 4.50'e ayarlanan Rodamin B çözeltilerinde 58.0 mV/onkat'lık eğim ve 5.0×10^{-7} M tayin limiti (LOD) ile doğrusal bir cevap sergiledi. Rodamin B-seçici sensörün cevap zamanı 5 saniyeden düşük olduğu ve pH 4.49-8.08 aralığında hidronyum iyonlarından etkilenmediği belirlendi. Sensörün analitik uygulaması Van Gölü, atık su ve çeşme suyunda başarıyla gerçekleştirildi.

Anahtar Kelimeler: Metal organik kafes yapısı, potansiyometrik sensör, Rodamin B tayini

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1. Introduction

The structure of Rhodamine B contains a carboxylic acid functional group on the benzene ring and an N,N-diethylamino group attached to the xanthene moiety [1]. Figure 1 shows the molecular structure of Rhodamine B. Rhodamine B is a synthetic xanthene dye with a wide range of applications. It is extensively used in the textile industry for dyeing cotton, wool, and synthetic fibers, and is also employed in the production of furniture and cosmetic products. Beyond industrial applications, Rhodamine B serves as a fluorescent tracer in analytical and photochemical techniques, biological assays, and microbiological studies. Its strong fluorescent properties make it especially valuable in hydrogeological applications, where it is used to trace and monitor water flow in both natural and engineered water systems. As a result, it is found in the wastewater of many industrial, chemical, biomedical and photochemical laboratories [2]. Rhodamine B is used illegally to impart natural color to food products. Contamination levels in products such as pepper powder, pepper oil, and pepper paste were found to range from 0.021 to 50 μg/g [3]. Rhodamine B causes acute poisoning, liver dysfunction, cardiovascular disease, cancer, premature birth, nausea, irritation of the skin, eyes and respiratory tract when ingested by humans. Experimentally, Rhodamine B has been shown to have carcinogenicity, reproductive and developmental toxicity, neurotoxicity, and chronic toxicity to humans and animals [4, 5]. Therefore, the determination of Rhodamine B is of great importance.

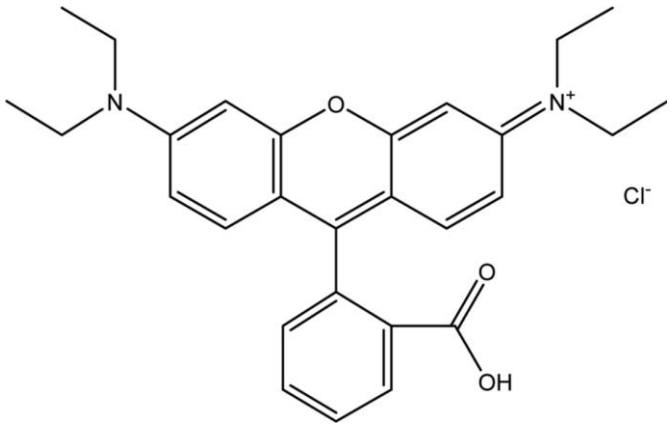


Figure 1. Chemical structure of Rhodamine B

Determination of Rhodamine B was carried out by Electrokinetic capillary chromatography [6], amperometry [7], high-pressure liquid fluorescence chromatography [8], reversed-phase high-performance liquid chromatography coupled with mass spectrometry [9], high-performance liquid chromatography combined with a fluorescence detector (FLD) [3], fluorimetry [10], extraction methods [11-13], voltammetry [14], surface-enhanced Raman spectroscopy [15], and ELISA [16]. However, these methods have disadvantages such as long analysis times, the need for preliminary separation steps (e.g., solid-phase extraction) and the use of expensive equipment. Therefore, it is important to develop a method for the determination of Rhodamine B that is cost-effective, simple, sensitive, and rapid.

Potentiometry is a powerful and versatile analytical method as it provides high sensitivity, accuracy, and precision as well as a wide linear range with low-cost instrumentation. It has several advantages, such as simplicity, low cost, speed, reliability, and not requiring expert technicians to perform the procedure. Since potentiometric methods do not require the application of an external potential, they are considered the simplest among all electroanalytical

techniques in terms of signal transmission [17]. Potentiometric ion selective electrodes are used in the determination of anionic and cationic species in many fields such as medicine, drug analysis, industrial and agricultural fields [18]. Studies on ion-selective electrodes began in the late 1960s and interest in ion-selective electrodes still continues to grow [19]. Ion-selective electrodes are the chemical sensors with the longest history and probably the most frequent routine application. Ion-selective electrodes are considered to be one of the most effective methods for the direct analysis of ionic species and indirect determination of non-ionic components in complex samples [20]. The field of clinical chemistry is the most important application area of ion-selective electrodes. The use of ion-selective electrodes in the analysis of samples containing multiple ionic species (such as water and soil) provides advantageous measurement data [21]. Ion-selective electrodes have many advantages such as short response time, excellent selectivity and affordability. ISEs offer many advantages, including short response times, excellent selectivity, and cost-effectiveness. Recently, metal-organic framework (MOF)-based materials have attracted considerable attention for enhancing the performance of ISEs due to their superior conductivity and specific ion-binding capabilities.

Metal–organic frameworks (MOFs) are porous materials constructed from metal ions or metal clusters coordinated to organic linkers. They possess exceptionally high surface areas. Due to the presence of organic linkers, MOFs are compatible with various polymers. This characteristic renders them superior to zeolites, and they can also be synthesized with tunable pore sizes [22–25]. MOFs have found applications in diverse fields such as gas adsorption, purification and storage, drug delivery, sensing, and catalysis [26]. Although MOFs have recently been widely employed in electrochemical sensor applications, their use in potentiometric sensors remains limited [27].

Among various metal-organic frameworks (MOFs), MIL-53 (Al) stands out as a promising candidate due to its tunable pore structure and excellent stability, making it a valuable material for enhancing the performance of ion-selective electrodes. The MIL-53(Al) structure consists of rod-like metallic secondary building units, in which aluminum (III) ions are connected via μ^2-OH bridging groups [28]. Much research has been done on MIL-53 compounds because they exhibit a high degree of reversible flexibility within their lattice structure. However, what makes this particular class of MOFs interesting for further investigation is their high thermal stability up to 500°C [29]. For instance, MIL-53(Al) has been used as an ionophore in sensors designed for the determination of pharmaceutical compounds such as imipramine hydrochloride [27] and maprotiline hydrochloride [30]. A potentiometric sensor based on ion pair was developed for the determination of Rhodamine B [31]. However, no potentiometric sensor based on MOF has been developed for the determination of Rhodamine B. In this study, for the first time, a MOF-based potentiometric PVC membrane ion-selective sensor was fabricated for the determination of Rhodamine B, thereby introducing a novel MOF-based approach for dye detection.

2. Material and Methods

2.1. Chemicals and Apparatus

Rhodamine B (ISOLAB, Germany) was obtained from the company. Tetrahydrofuran (THF), high-molecular-weight-poly (vinyl chloride) (PVC), MIL-53 (Al), nitrophenyloctylether (NPOE), bis(2-ethyl)hexyl sebacate (DOS) and dibutylphthalate (DBP) were sourced from Sigma-Aldrich (Germany). The epoxy (TP3100) and hardener (Desmodur RFE) employed in the preparation of the solid-contact were acquired from Denlaks (Turkey) and Bayer (Germany) companies, respectively. All chemicals employed in solution preparation throughout this study were analytical grade and procured from Sigma-Aldrich (Germany). For the potentiometric application, wastewater, Van Lake water and tap water samples taken from Van were used. All solutions were prepared with 18.3 MΩ deionized pure water. A Gamry (USA) brand saturated Ag/AgCl electrode served as the reference electrode throughout the potential measurements. All potentiometric measurements were conducted using a custom-made computer-controlled potentiometric measurement system.

2.2 Preparing the Sensors

The sensors were first coated with solid contact. Solid contact was prepared by adding THF to 35% (w/w) epoxy, 15% (w/w) hardener and 50% (w/w) graphite to obtain a suitable homogenized mixture. Then, the open end of a copper wire was dipped into this mixture and the wire was coated with solid contact. It was then left to dry in the dark at room temperature for 24 hours. Then, the membranes were prepared and the surface of the solid contacts were covered with the membrane. The composition of the membranes consists of PVC, different types of plasticizers, MIL-53 (Al) and sometimes KTpClPB (potassium tetrakis(4-chlorophenyl)borate). Membranes were prepared by dissolving 100 mg of total membrane mass in 1 mL of THF. It was dried at room temperature in the dark for 24 hours. Prepared sensors were conditioned in 1.0×10^{-2} M Rhodamine B solutions for 12 hours.

3. Results and Disscussion

3.1. Determination of Optimum Membrane Composition

The potentiometric properties of a PVC membrane ion-selective sensor are highly dependent on the membrane composition. Twelve different sensors were obtained with different types and ratios of ionophore, plasticizer, ionizer and PVC. The sensor with the best performance was determined. The membrane compositions tested for the development of the Rhodamine B-selective sensor and their potentiometric performance properties are given in Table 1 and Table 2, respectively.

Table 1. The studied membrane compositions for the membrane optimization study

	Membrane Composition (%w/w)					
	Polymer	**Plasticizer**			**Ionophore**	**Ionic Additive**
Sensor No	**PVC**	**NPOE**	**DBF**	**DOS**	**MIL-53**	**KTpCIPB**
A-1	26.0	67.0	-	-	6.0	1.0
A-2	26.0	68.0	-	-	6.0	-
A-3	26.0	-	67.0	-	6.0	1.0
A-4	26.0	-	68.0	-	6.0	-
A-5	26.0	-	-	67.0	6.0	1.0
A-6	**26.0**	**-**	**-**	**68.0**	**6.0**	**-**
A-7	32.0	64.0		-	3.0	1.0
A-8	32.0	65.0	-	-	3.0	-
A-9	32.0	-	64.0	-	3.0	1.0
A-10	32.0	-	65.0	-	3.0	-
A-11	32.0	-	-	64.0	3.0	1.0
A-12	32.0	-	-	65.0	3.0	-

Table 2. Potentiometric performance characteristics of electrodes made from different membrane compositions for Rhodamine B solutions prepared in deionized water

Sensor No	Slope, mV/decade	Detection Limit, M	Linear Range, M	R^2
A-1	60.0	1.0×10^{-7}	1.0×10^{-6}-1.0×10^{-2}	0.9898
A-2	47.4	1.0×10^{-6}	1.0×10^{-6}-1.0×10^{-2}	0.9934
A-3	62.5	5.0×10^{-7}	1.0×10^{-6}-1.0×10^{-2}	0.9936
A-4	55.0	1.0×10^{-7}	1.0×10^{-6}-1.0×10^{-2}	0.9883
A-5	62.8	5.0×10^{-7}	1.0×10^{-6}-1.0×10^{-2}	0.9923
A-6	**52.2**	**1.0×10^{-7}**	**1.0×10^{-7}-1.0×10^{-2}**	**0.9902**
A-7	66.1	1.0×10^{-6}	1.0×10^{-6}-1.0×10^{-2}	0.9928
A-8	52.3	1.0×10^{-6}	1.0×10^{-6}-1.0×10^{-2}	0.9701
A-9	67.3	1.0×10^{-6}	1.0×10^{-6}-1.0×10^{-2}	0.9935
A-10	52.4	1.0×10^{-6}	1.0×10^{-6}-1.0×10^{-2}	0.9875
A-11	64.0	1.0×10^{-6}	$1.0x10^{-6}$-1.0×10^{-2}	0.9914
A-12	55.9	1.0×10^{-6}	$1.0x10^{-6}$-1.0×10^{-2}	0.9936

3.2. Determination of Detection Limit, Linear Working Range, and Slope

Measurements taken in a series of Rhodamine B standard solutions (1.0×10^{-2} M-1.0×10^{-7} M) prepared in deionized water were used to create the calibration chart. The resulting calibration graph was used for slope, linear working range and R^2 calculations. The detection limit of the Rhodamine B-selective sensor was determined according to IUPAC [32]. For this purpose, potential measurements of low and high concentrations of Rhodamine B were made at 25±1°C. The potential-time graph obtained for Rhodamine B solutions at different concentrations with the Rhodamine B-selective sensor is shown in Figure 2 and its calibration graph is shown in Figure 3. The sensor shows a linear response in Rhodamine B solutions prepared in deionized water over the concentration range of 1.0×10^{-7} M to 1.0×10^{-2} M with a slope of 52.2 mV/decade and a detection limit of 1.0×10^{-7} M.

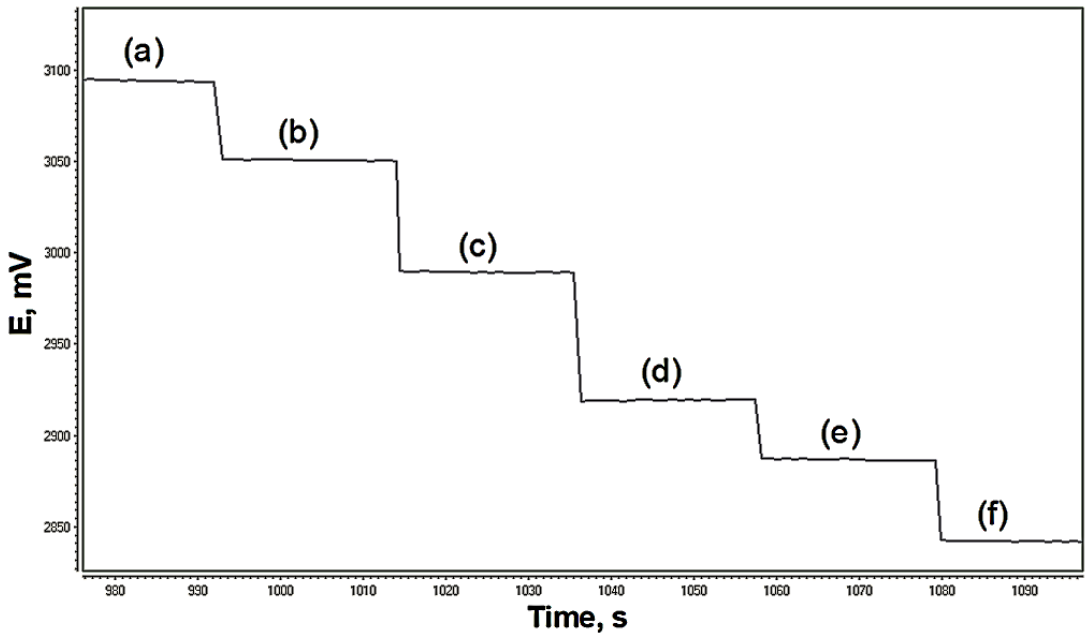


Figure 2. Potentiometric responses of the Rhodamine B-selective sensor in Rhodamine B solutions prepared in deionized water in the concentration range of 1.0×10^{-2} M-1.0×10^{-7} M. (a) 1.0×10^{-2} M (b) 1.0×10^{-3} M (c) 1.0×10^{-4} M (d) 1.0×10^{-5} M (e) 1.0×10^{-6} M (f) 1.0×10^{-7} M

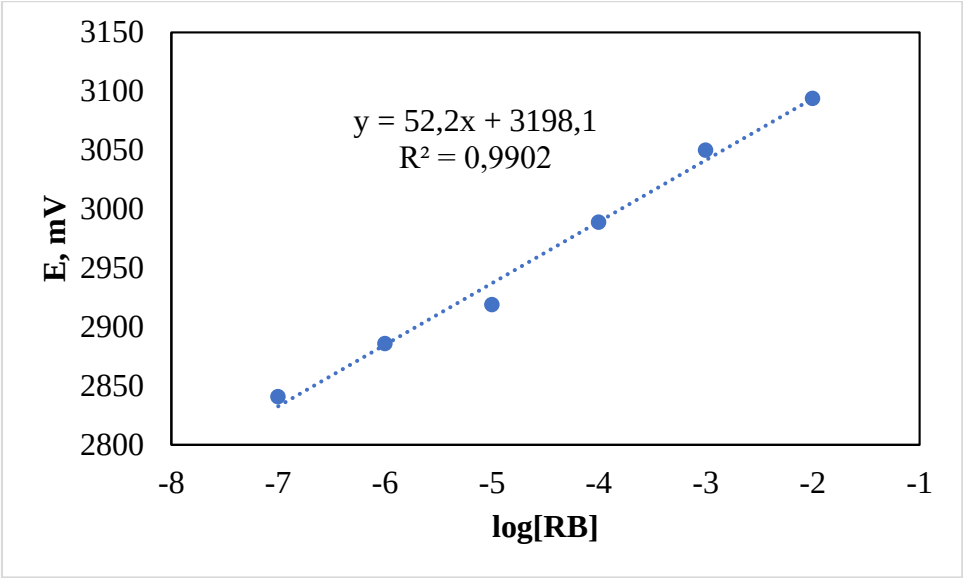


Figure 3. Calibration graph obtained for Rhodamine B standard solutions prepared in deionized water using sensor number A-6

The potentiometric responses of the Rhodamine B-selective sensor number A-6, adjusted to pH 4.50 using HCl and NaOH for 1.0×10^{-2} M-1.0×10^{-6} M Rhodamine B solutions, are shown in Figure 4. The calibration graph obtained is also given in Figure 5. The detection limit of the Rhodamine B-selective sensor was determined according to IUPAC [32]. For this purpose, Rhodamine B potential measurements were made at 25±1°C. Sensor number A-6 showed linearity in the concentration range of 1.0×10^{-2}-1.0×10^{-6} M with a concentration change of 58.0 mV/decade, and the detection limit of the proposed Rhodamine B-selective sensor was calculated as 5.0×10^{-7} M.

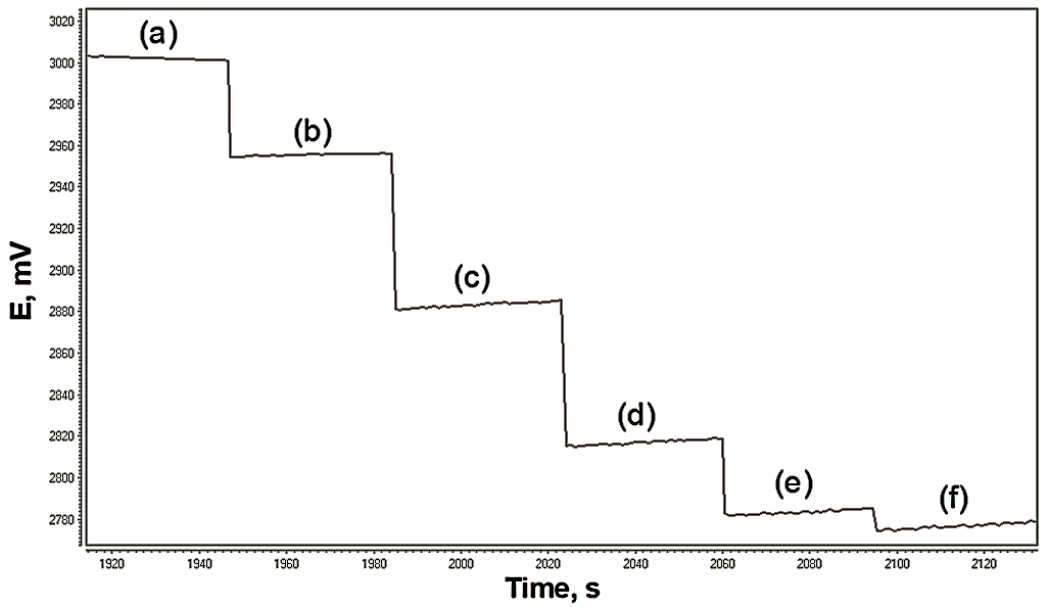


Figure 4. Potentiometric responses of the Rhodamine B-selective sensor to Rhodamine B solutions in the concentration range of 1.0×10^{-2} M-1.0×10^{-7} M adjusted to pH 4.50. (a) 1.0×10^{-2} M (b) 1.0×10^{-3} M (c) 1.0×10^{-4} M (d) 1.0×10^{-5} M (e) 1.0×10^{-6} M (f) 1.0×10^{-7} M

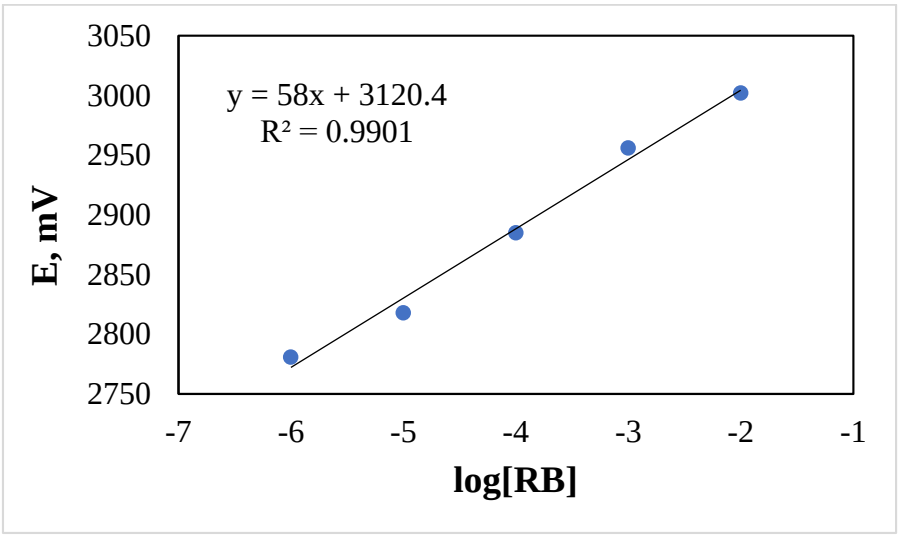


Figure 5. Calibration graph obtained from standard Rhodamine B solutions in the concentration range of 1.0×10^{-2} M-1.0×10^{-6} M adjusted to pH 4.50 using the Rhodamine B-selective sensor

3.3. Determination of Repeatability of Rhodamine B-Selective Sensor

In order to determine the repeatability of the Rhodamine B selective sensor, consecutive measurements were carried out in 1.0×10^{-3}, 1.0×10^{-4} and 1.0×10^{-5} M Rhodamine B solutions with pH adjusted to 4.50. The potential-time graph showing the repeatability of the Rhodamine B-selective sensor is given in Figure 6. The means and standard deviations for 1.0×10^{-3} M, 1.0×10^{-4} M and 1.0×10^{-5} M Rhodamine B solutions (pH=4.50) were calculated as 2959.6±2.3 mV, 2896±0.4 mV and 2831.8±1.1 mV, respectively. The potential values measured with the

Rhodamine B-selective sensor in 1.0×10^{-3}, 1.0×10^{-4} and 1.0×10^{-5} M Rhodamine B solutions (pH=4.50) are given in Table 3.

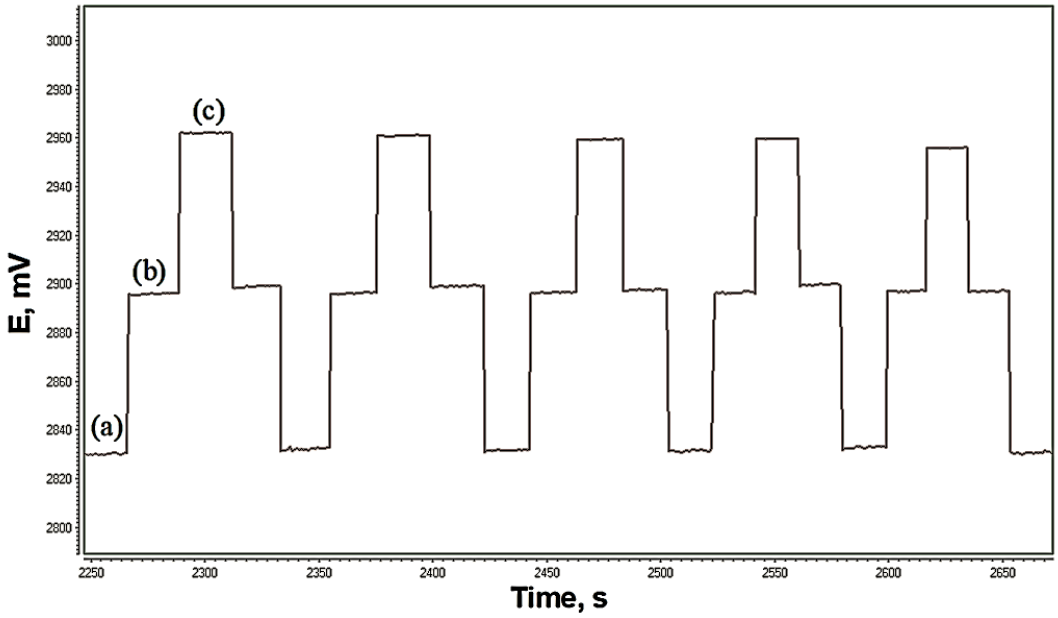


Figure 6. Repeatability of Rhodamine B-selective sensor in (a) 1.0×10^{-5} M, (b) 1.0×10^{-4} M and (c) 1.0×10^{-3} M Rhodamine B solutions (pH=4.50)

Table 3. Potential values measured with Rhodamine B-selective sensor in 1.0×10^{-3} M, 1.0×10^{-4} M and 1.0×10^{-5} M Rhodamine B solutions (pH=4.50)

Concentration (M)	**1**	**2**	**3**	**4**	**5**	**$\bar{x}\pm s$**
1.0×10^{-3}	2962	2961	2959	2960	2956	2959.6±2.3
1.0×10^{-4}	2896	2896	2895	2896	2896	2896.0±0.4
1.0×10^{-5}	2832	2832	2832	2833	2830	2831.8±1.1

3.4. Determination of Response Time of Rhodamine B-Selective Sensor

In order to determine the response time of the sensor, the calibration solutions were continuously mixed at a constant speed. The measurements were taken with the sensor from low concentration to high concentration and from high concentration to low concentration. The average of the 95% of the time at which the potentials became stable was determined as the response time of the sensor. The time required for the sensor to reach equilibrium in 1.0×10^{-4} M and 1.0×10^{-3} M Rhodamine B solutions (pH=4.50) is shown in Figure 7. The average response time of the sensor was determined to be less than 5 seconds.

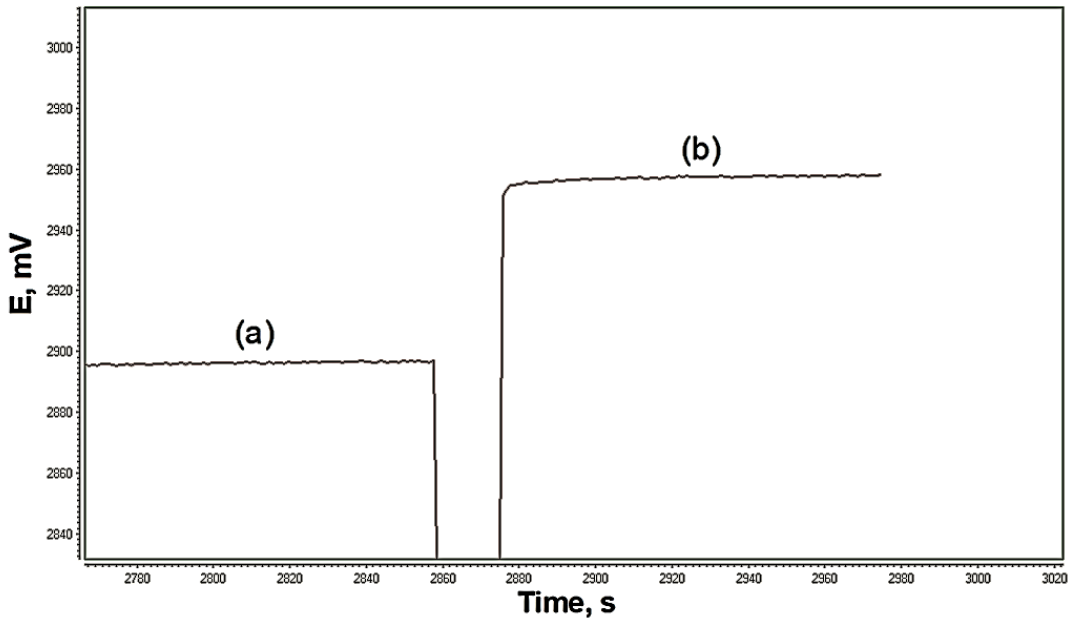


Figure 7. Response time of Rhodamine B-selective sensor in (a) 1.0×10^{-4} M and (b) 1.0×10^{-3} M Rhodamine B solutions

3.5. Determination of pH Working Range of Rhodamine B-selective Sensor

To determine the pH working range of the Rhodamine B-selective sensor, 25 mL of 1.0×10^{-3} M Rhodamine B solutions were prepared. The prepared Rhodamine B solutions were mixed at a certain speed and at this time, the Rhodamine B-selective sensor numbered A-6, the reference electrode and also the pH meter were immersed in the solutions. The pH value of the solution was changed by adding HCl and NaOH to the Rhodamine B solution little by little. The pH value and corresponding potential values were recorded each time an acid and base were added to the Rhodamine B solution. The potential value corresponding to the pH values was plotted on the graph. The pH study graph is given in Figure 8. Since there was no significant change in the potential in the pH range of 4.49-8.08, it is clear that the potential of the sensor was not affected by hydronium ions in this pH range. The pH working range of the Rhodamine B-selective sensor was determined as 4.49-8.08. Below a pH of 4.49, the observed increase in measured potential can be attributed to the interference effect of hydronium ions present in the measurement media at elevated concentrations. Conversely, it was observed that above pH 8.08, the sensor potentials began to decline rapidly. This decline is rationalized by the gradual reduction in the amount of protonated rhodamine B at higher pH levels, aligning with anticipated behavior.

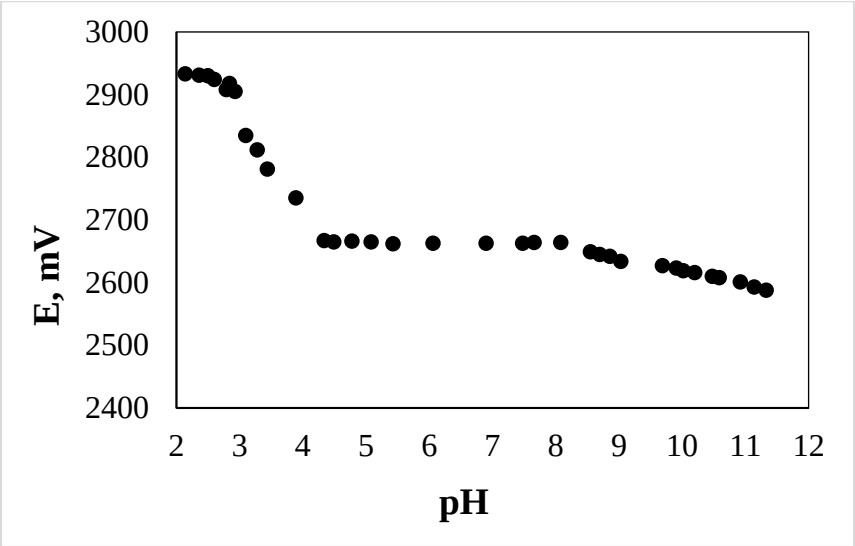


Figure 8. pH working range of Rhodamine B-selective sensor

3.6. Determination of Selectivity of Rhodamine B-Selective Sensor

To determine the effects of some alkali metals, heavy metals, and alkaline earth metals on the response of the Rhodamine B-selective sensor, selectivity coefficients against these species were calculated using the separate solution method (E_A=E_B). Potentiometric measurements of commonly occurring ions were taken in the concentration range of 1.0×10^{-6} M-1.0×10^{-2} M. The potential value obtained at a concentration of 1.0×10^{-2} M of the interfering ion was written in the calibration graph obtained for Rhodamine B and the selectivity coefficient was calculated according to the separate solution method. The graph showing the selectivity of the Rhodamine B-selective sensor is given in Figure 9. The selectivity coefficients of the Rhodamine B-selective sensor calculated according to the separate solution method are given in Table 4. When the selectivity coefficient values in Table 4 are examined, it can be said that the developed PVC membrane Rhodamine B-selective sensor exhibits a highly selective potentiometric response. The most interfering ions on the potential response of the sensor were NH_4^+ and K^+. Even in the presence of these ions, the developed PVC membrane rhodamine B-selective sensor exhibited a selective response of more than approximately 1000 times for the target analyte.

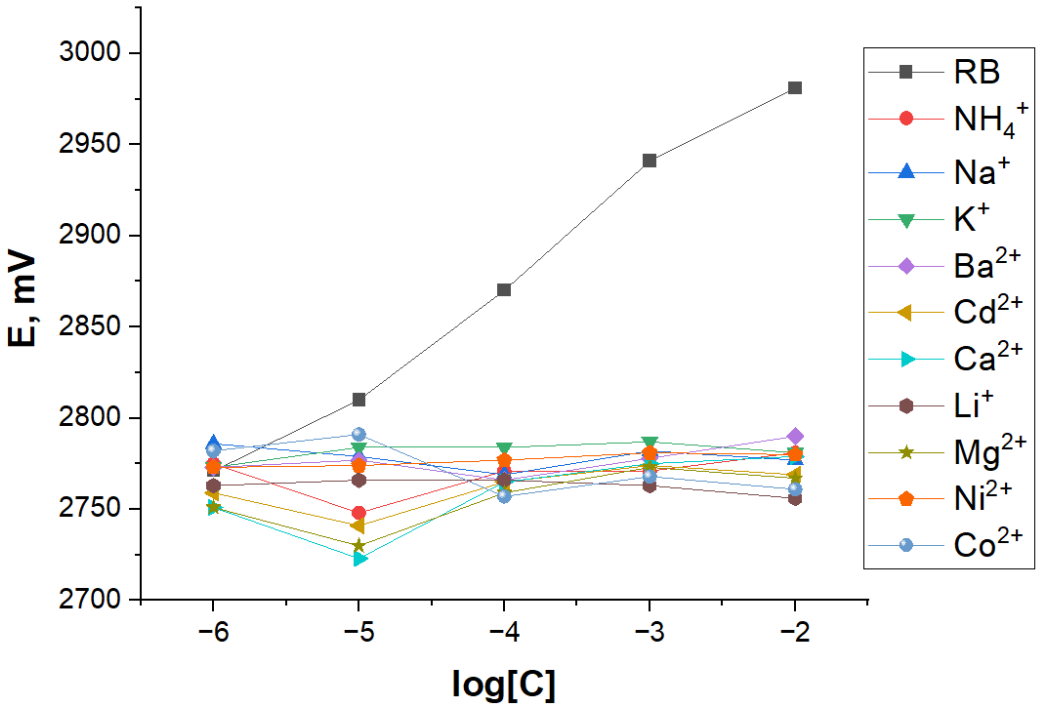


Figure 9. Graph showing the selectivity of the Rhodamine B-selective sensor

Table 4. The calculated selectivity coefficients of Rhodamine B selective sensor for studied interferents

Interferents	$K_{RB/Interferent}$	$-\log K_{RB/Interferent}$
NH_4^+	2.04×10^{-4}	3.69
K^+	2.04×10^{-4}	3.69
Na^+	1.69×10^{-4}	3.77
Li^+	7.07×10^{-5}	4.15
Ba^{2+}	2.95×10^{-5}	4.53
Ni^{2+}	1.94×10^{-5}	4.71
Ca^{2+}	1.86×10^{-5}	4.73
Cd^{2+}	1.23×10^{-5}	4.91
Mg^{+2}	1.12×10^{-5}	4.95
Co^{2+}	8.71×10^{-6}	5.06

3.7. Determination of Life-Time

In order to determine the life-time of the Rhodamine B selective sensor, measurements were taken every day in the concentration range of 1.0×10^{-2} M-1.0×10^{-6} M in standard Rhodamine B solutions adjusted to pH 4.50 using the Rhodamine B selective sensor. The obtained slope values were plotted against time. Before each calibration run, the Rhodamine B selective sensor was conditioned in 1.0×10^{-2} M Rhodamine B solution for half an hour. The sensors were kept in the dark when not in use. The plot illustrating the slopes of the proposed electrode over time Figure 10 shows that there is no significant change in the slope of the sensor over a period of 23 days. We can say that the recommended sensor can be used for 23 days without any sensitivity problems. Consequently, the life-time of the Rhodamine B-selective sensor is 23 days.

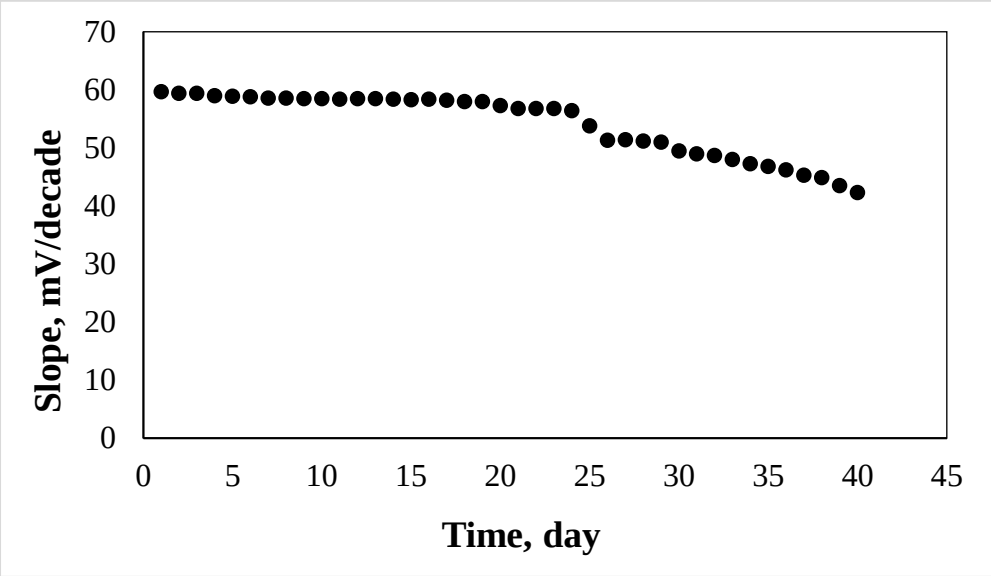


Figure 10. Graph showing the life-time of the Rhodamine B-selective sensor

3.8. Analytical Application of Rhodamine B-Selective Sensor

Analytical application of the sensor was carried out by adding Rhodamine B to Van Lake water, wastewater, and tap water samples and directly determining the Rhodamine B content in the samples. Samples S1 (tap water, 1.0×10^{-3} M), S2 (tap water, 1.0×10^{-4} M), S3 (wastewater, 1.0×10^{-3} M), S4 (Van Lake water, 1.0×10^{-3} M), S5 (Van Lake water, 1.0×10^{-4} M) were prepared. The pH of all samples and 1.0×10^{-2} M-1.0×10^{-6} M Rhodamine B solutions were adjusted to 4.50 (with 1.0 M HCl and 1.0 M NaOH). Calibration graph was obtained using Rhodamine B-selective sensor in 1.0×10^{-2} M-1.0×10^{-6} M Rhodamine B solutions with pH adjusted to 4.50. The potentiometric responses obtained for the measurement of samples S1, S2, S3, S4 and S5 are shown in Figure 11, Figure 12 and Figure 13, respectively. The corresponding sample contents were calculated using the potential values recorded from the sample solutions and the relevant calibration equation. The statistical analysis results obtained are given in Table 5.

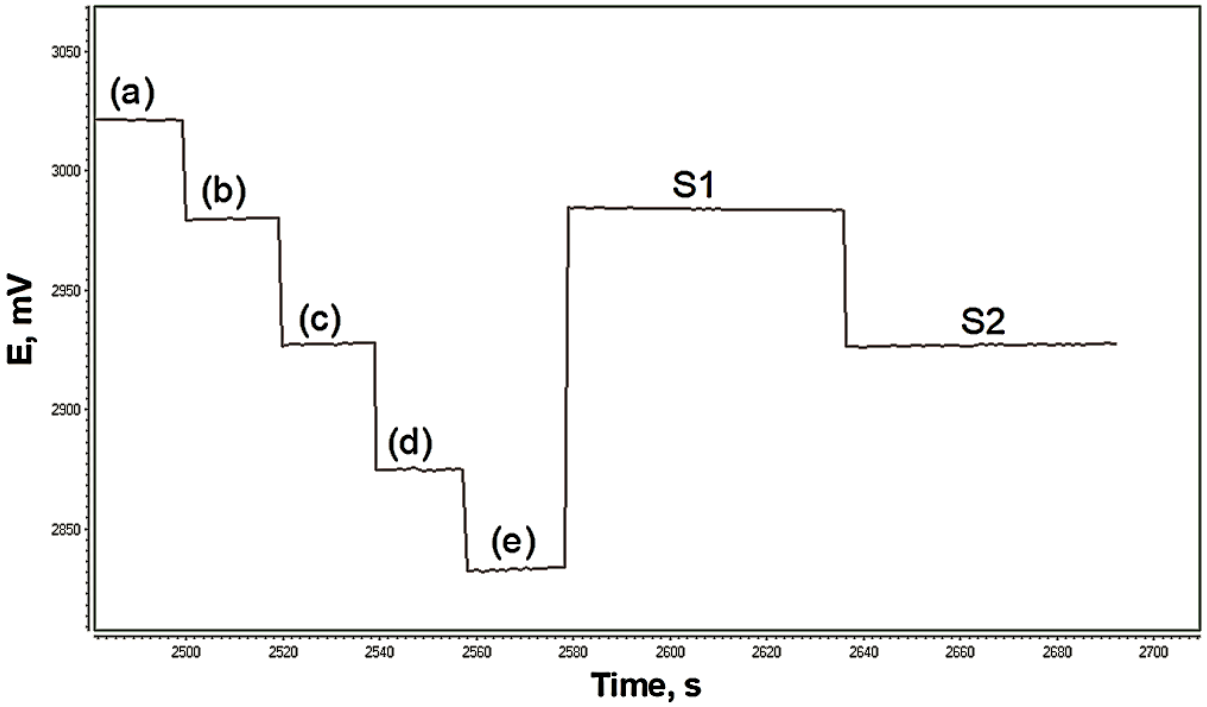


Figure 11. Response of Rhodamine B-selective sensor to Rhodamine B solutions in the concentration range of 1.0×10^{-2} M-1.0×10^{-6} M (pH 4.50), S1 and S2 tap water samples. (a) 1.0×10^{-2} M (b) 1.0×10^{-3} M (c) 1.0×10^{-4} M (d) 1.0×10^{-5} M (e) 1.0×10^{-6} M

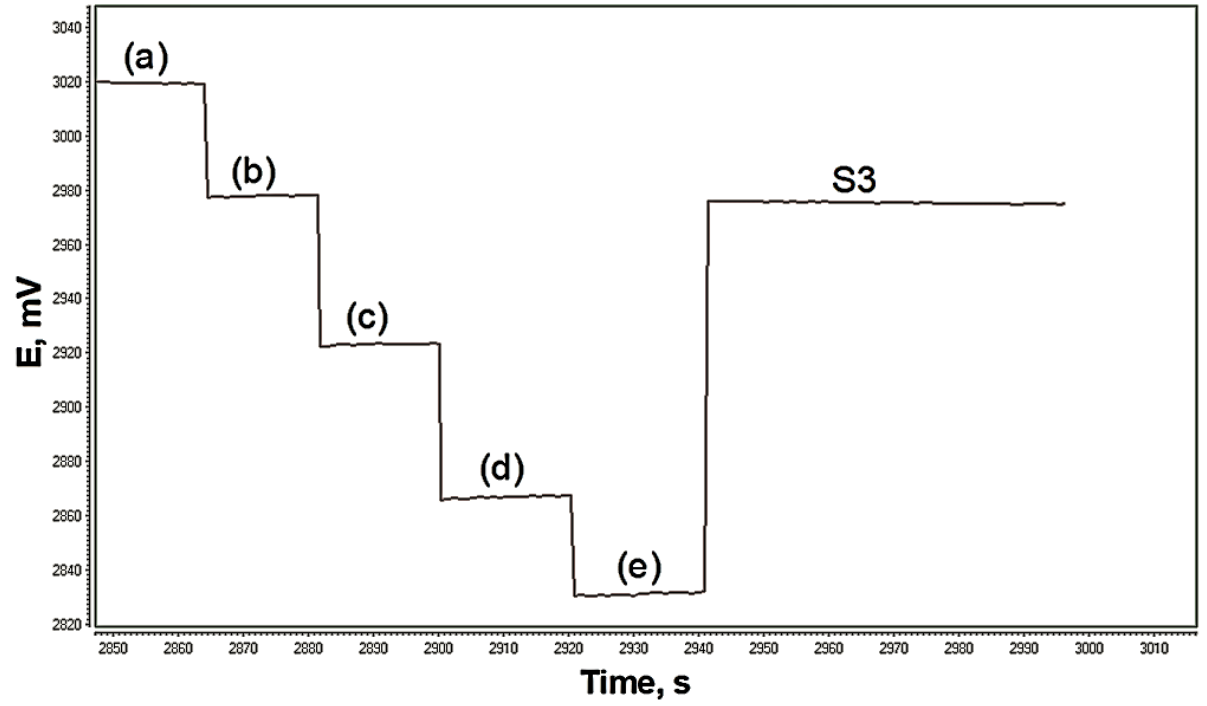


Figure 12. Response of Rhodamine B-selective sensor to Rhodamine B solutions in the concentration range of 1.0×10^{-2} M-1.0×10^{-6} M (pH 4.50) and S3 sample prepared in wastewater. (a) 1.0×10^{-2} M (b) 1.0×10^{-3} M (c) 1.0×10^{-4} M (d) 1.0×10^{-5} M (e) 1.0×10^{-6} M

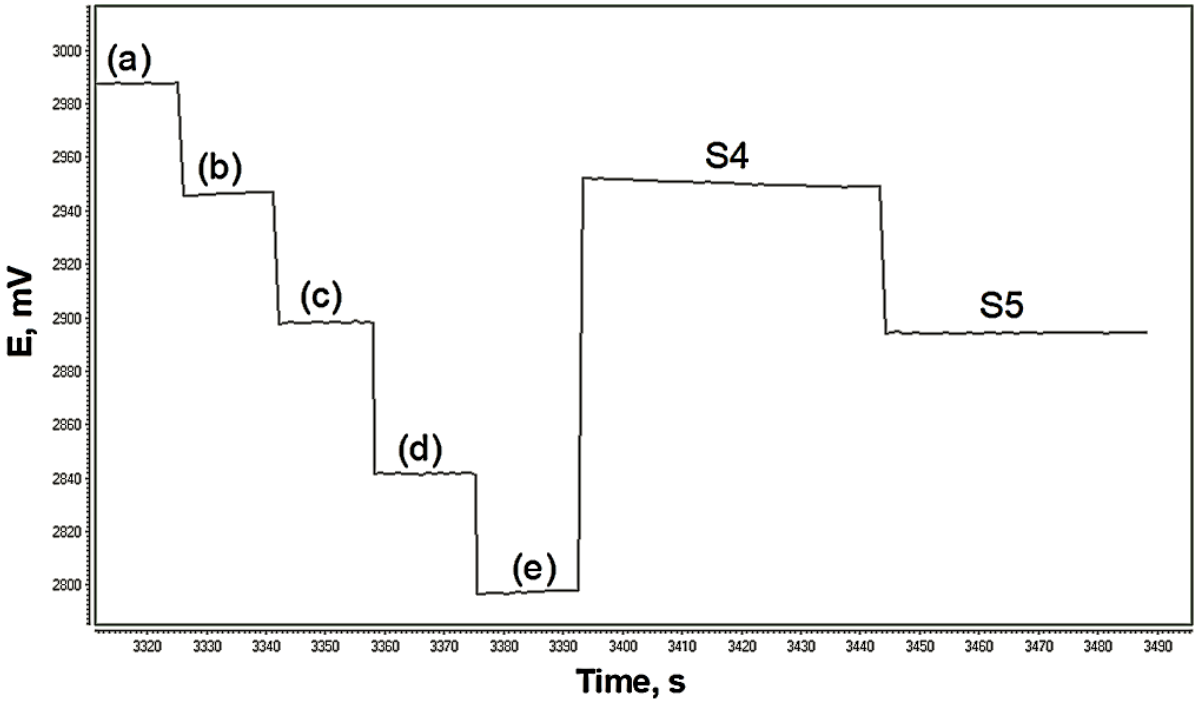


Figure 13. Response of Rhodamine B-selective sensor to Rhodamine B solutions in the concentration range of 1.0×10^{-2} M-1.0×10^{-6} M (pH 4.50), S4 and S5 Van Lake water samples. (a) 1.0×10^{-2} M (b) 1.0×10^{-3} M (c) 1.0×10^{-4} M (d) 1.0×10^{-5} M (e) 1.0×10^{-6} M

Table 5. Statistical evaluation of sample analyses with Rhodamine B-selective sensor using potentiometric analysis results

	Added (mg/mL)	Found (mg/mL)	Recovery (%)	Er (%)
S1 (Tap water)	4.79×10^{-1}	4.69×10^{-1}	97.91	2.09
S2 (Tap water)	4.79×10^{-2}	4.78×10^{-2}	99.79	0.21
S3 (Wastewater)	4.79×10^{-1}	4.65×10^{-1}	97.08	2.92
S4 (Van Lake water)	4.79×10^{-1}	4.83×10^{-1}	100.84	0.83
S5 (Van Lake water)	4.79×10^{-2}	4.77×10^{-2}	99.58	0.41

4. Conclusion

MIL-53 (Al), a metal organic framework, was used as the ionophore in the membrane composition of the Rhodamine B-selective sensor. When compared in terms of potentiometric performance properties, the optimum membrane composition was determined as 6% MIL-53

(Al), 26% PVC, 68% DOS. The response time of the sensor was determined to be less than 5 seconds. The sensor has a life-time of 23 days. The pH range in which the Rhodamine B-selective sensor was not affected by hydronium ions was determined to be 4.49-8.08. The developed Rhodamine B-selective sensor was successfully applied in the studies to determine the 1.0×10^{-3} M and 1.0×10^{-4} M Rhodamine B content in tap water, Van Lake water, and wastewater. The developed sensor has many advantages such as practical, wide linear working range, short response time, economical, sensitivity, low detection limit and high selectivity. In the literature, only one potentiometric sensor has been encountered so far for the determination of Rhodamine B [31]. It is given in comparison with the sensor we developed in Table 6. In this study, the potentiometric sensor we developed for the determination of Rhodamine B is easier to prepare and has a shorter response time.

Table 6. Comparison of the developed sensor with various reported Rhodamine B-selective sensors

Linear Range, M	Response Time, s	Life-time, day	pH Working Range	Detection Limit, M	Reference No
1.0×10^{-6}- 1.0×10^{-3}	8	28	3.00–7.00	5.0×10^{-7}	[31]
1.0×10^{-6}-1.0×10^{-2}	<5	23	4.49-8.08	5.0×10^{-7}	This study

Ethics in Publishing

There are no ethical issues regarding the publication of this study

Author Contributions

The authors contributed equally to the work.

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